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LOCOMOTIVE BUILDING

By FRANKLIN D. JONES

PART III

FRAMES AND CYLINDERS

CONTENTS

Machining Locomotive Frames - - - - - - 3
Machining Locomotive Cylinders - - - - - 23

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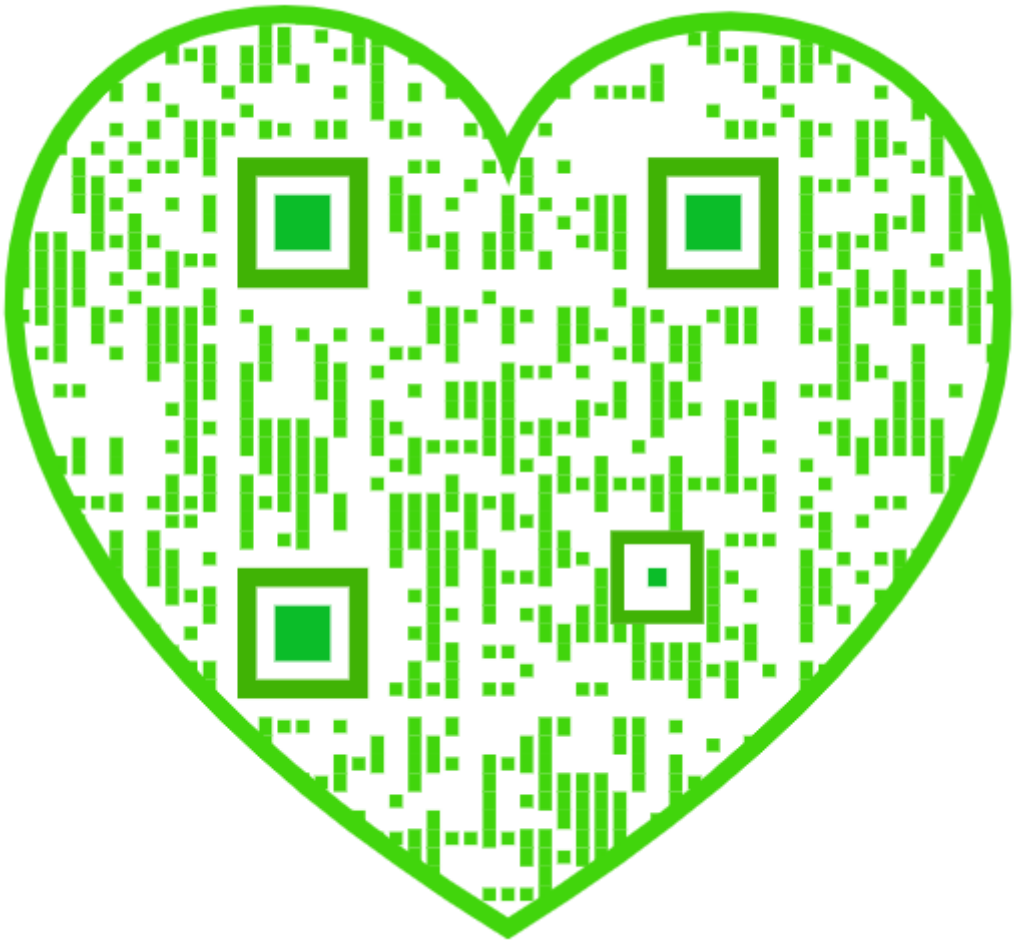

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CHAPTER I

MACHINING LOCOMOTIVE FRAMES*

The frame of a locomotive might appropriately be called the foundation or backbone, as it holds in position the driving and reversing mechanism, spring rigging and other important parts which form the running gear. The complete frame is composed of right and left sections which extend longitudinally from either the cylinders or "bumper" at the front, to the foot-plate at the rear of the fire-box. These sections are not always composed of one continuous piece, but are often formed of two or three parts which are joined or spliced together by tightly fitting taper bolts. The general arrangement of the frame depends, of course, upon the design of the locomotive. When the frame is erected, the two sections or halves are bolted to the cylinder castings and they are further stiffened and held in alignment by cross-ties and braces. This matter of bracing is very important, as a rigid structure is necessary to withstand the severe strains to which the frame is subjected. As the driving wheels are held in position by the frame, the latter not only receives heavy fore-and-aft thrusts, but also severe lateral strains, especially when the locomotive strikes a curve at high speed; consequently, if the frame is weak and yielding, a fracture is only a question of time, and, from the beginning, there is likely to be more or less trouble with the driving wheel journals and rod bearings because the running gear is not held in alignment. Designers have had considerable difficulty in providing adequate frame braces on locomotives equipped with the Stephenson valve mechanism, because of the room required between the frames for the eccentric rods, links, etc. This difficulty, however, has been largely overcome by the extensive use of the Walschaerts valve gear which is located entirely outside of the driving wheels and permits braces to be used without interfering with the valve motion, at a point where they are needed most.

The machining of a locomotive frame would be a rather difficult proposition for the average machine shop, because of the size of the work and its unwieldy proportions, but in a modern locomotive shop, the operation is commonplace. At the Juniata shops of the Pennsylvania Railroad, the methods of handling this class of work are of exceptional interest, principally because of the high standard of efficiency maintained for the various machining operations. While this work is comparatively rough, if judged by the toolmaker's standards, considerable accuracy is necessary for certain surfaces, but the framework from start to finish is particularly noteworthy as an example of rapid machining rather than skillful and accurate work. The Juniata shops have, under normal conditions, a capacity for building a complete locomotive every day, and this rate is sometimes exceeded, so that the

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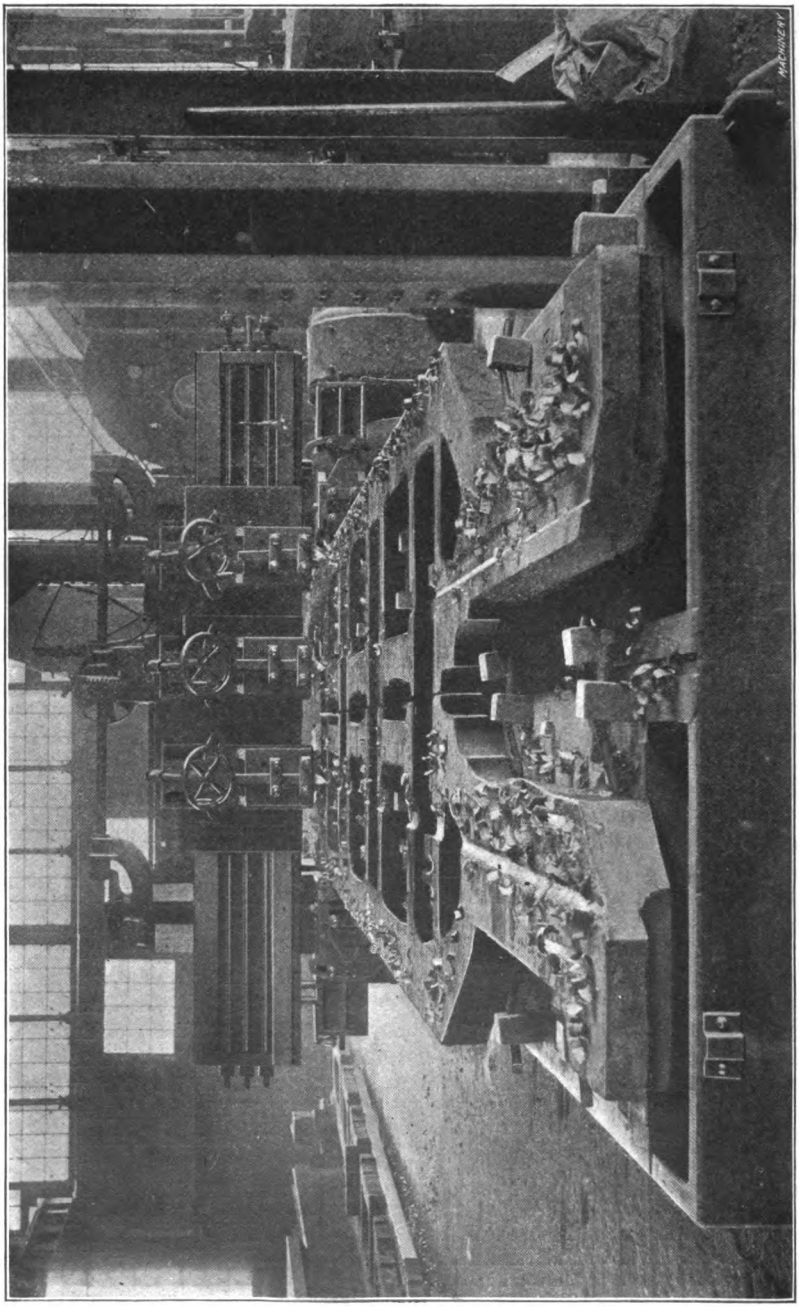

Fig. 1. Planing Two Frames simultaneously on a Powerful Planer equipped with Five Tools

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machining of frames is an everyday occurrence. Practically all of the locomotives built in these shops at the present time, are equipped with cast-steel frames instead of wrought-iron frames which were used almost exclusively a few years ago. Frames that are cast are much cheaper than the forged type, and another advantage of using cast steel is that pads or other projections can be easily and neatly formed on the frame pattern.

Straightening and Planing the Frames

The cast-steel frames are usually warped more or less as they come from the foundry, owing to unequal cooling, and it is necessary to

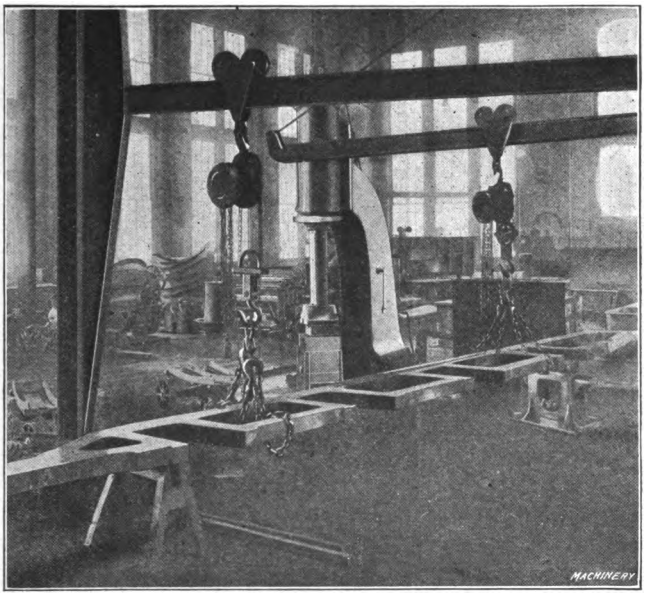

Fig. 2. Where the Warped Frames are straightened prior to Machining

straighten them prior to machining. This straightening is done under a large steam hammer as indicated in Fig. 2. The frame is heated sufficiently to insure a permanent "set" when straightened, and it is made approximately straight by giving it a few blows with the hammer. The work is then ready for the first machining operation which is that of planing the sides and edges. Two frames or sections are planed simultaneously on a very rigid planer having five tool-heads. A view of this machine taking a roughing cut over the sides of two frames is shown in Fig. 1. The work is held on the platen by screw-stops and toe-dogs or "spuds" which are placed in an inclined position to force the work down. Stops are also set against the frames at the most advantageous positions to take the longitudinal thrust of the cut. Part of the time, all five planing tools are at work, the three tool-heads on the cross-rail being used to plane the sides of the two sections, while

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the right and left side-heads plane the edges. The three upper tools are started so that each rough planes about one-third of the surface formed by the two castings. In this way the roughing is, of course, done in much less time than would be required if an ordinary two-head machine were employed. As many of these castings have spongy, sandy spots, blow-holes or similar defects on the cope side, a generous allowance is left for planing in order to remove all porous material. Owing to the power of this machine, very heavy cuts can be taken without difficulty, as indicated in the illustration Fig. 1. The planer is motor-driven, and momentarily as much as 90 horsepower is required

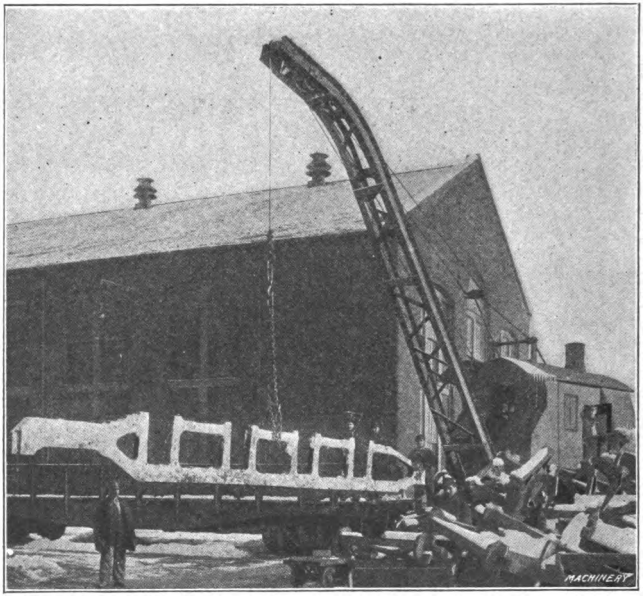

Fig. 3. Cast-steel Locomotive Frame on its Way to the Shop

for driving, owing to the heavy "hogging" cuts which are taken in the tough cast steel. When roughing, the tools frequently cut to a depth of from 1/2 to 3/4 inch with a feed of 3/16 inch. The average depth of cut for the five tools, however, would be somewhat less than the figures given. After the three heads on the cross-rail are started, the right and left side-heads are set for planing the edges. The work is set up for rough planing the first side, with the top edge of each section outward. This is done so that the top edges can be finished with reference to pads for braces or brackets which are located on the inside of the top and bottom rails of the frames. After the roughing cuts on one side are completed, the finishing cuts are taken with broad flat tools which are given a feed varying from 1 inch to 1¼ inch per stroke. Only two of the cross-rail heads are used for finishing, so that each frame can be planed by a continuous cut in order to obtain a smooth surface free from ridges. The frames are next turned over for rough-

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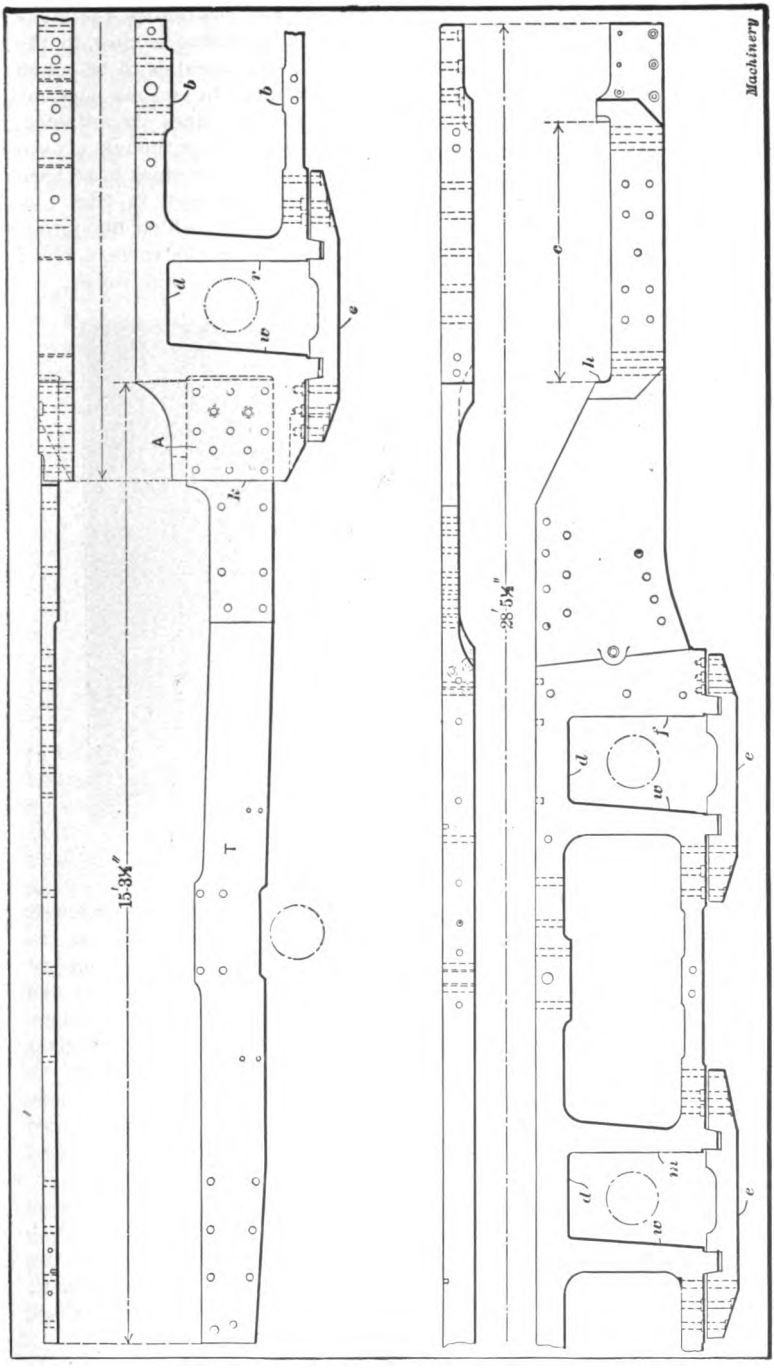

Fig. 4. Frame for a Passenger Locomotive of the 4-6-2 Type

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ing and finishing the opposite side, reversing the position of the work illustrated in Fig. 1. The opposite edge of each frame is now in the outward position, thus permitting the ends of the pedestals to be rough planed. The finishing tools are set for planing the second side by means of a post or height gage to which the cutting edges are adjusted. In this way the proper thickness is quickly obtained, although a fixed caliper gage is used to check this dimension. After the sides have been finished in this manner, a frame of the type illustrated in Fig. 4 is planed at *A* for the reception of the trailer frame *T* which fits into a pocket as shown. This pocket, in turn, is finished to the correct width and depth in another machine. This completes the planer work.

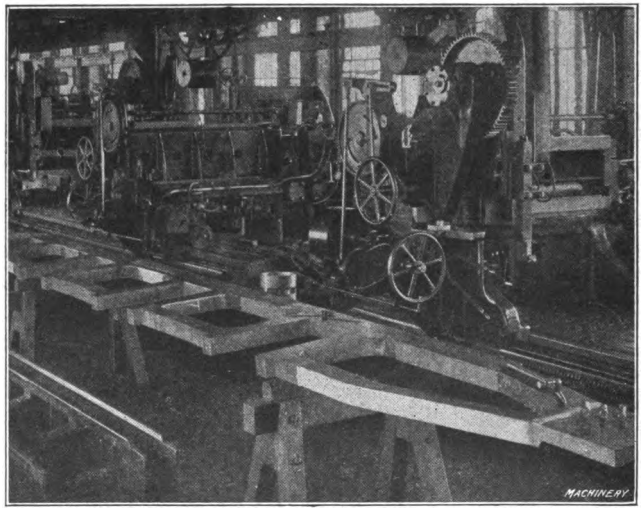

Fig. 5. Frame mounted on Horses for Laying-out Operation

Laying Out the Frames

The frames are next laid out for slotting, though this operation is only necessary for every fifth or seventh frame (depending on the size) owing to the method of slotting them in stacks, as will be explained later. The work is placed on horses (as shown in Fig. 5) and steel templets are used to give the required outline. One of these templets conforms to the shape of the pedestal jaws and another gives the outline for the cylinder fit at the front end. Before placing the templets on the frame, the surfaces on which finished lines are to be scribed, are moistened with water and then coated with a soft red stone called "keel." This leaves a dull red finish on which the scribed lines are easily seen.

The templets are aligned by the planed edge of the frame and enable the required outline to be quickly scribed on the finished surface. A number of bolt holes which cannot be drilled to good advantage by the use of jigs are also laid out by the use of templets which have small holes corresponding in location with the holes to be drilled and these

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are transferred to the work by using a light punch. After the templet is removed, two concentric circles are stamped around each center with special punches similar to those shown in Fig. 6. These punches have V-shaped annular ridges which form neat rings or grooves, one of which represents the size of the hole while the other remains as a "witness" to show whether or not the hole has been drilled central. The punches are made in various sizes and they are much superior to the old method of scribing and dotting a circle, when laying out holes.

Slotting the Frames

The slotting operation, which is the next in the regular order, is performed by the large machine shown in Fig. 7. A stack of from five to seven frames (the number depending on the size), can be slotted simultaneously, so that it is only necessary to lay out the one which is

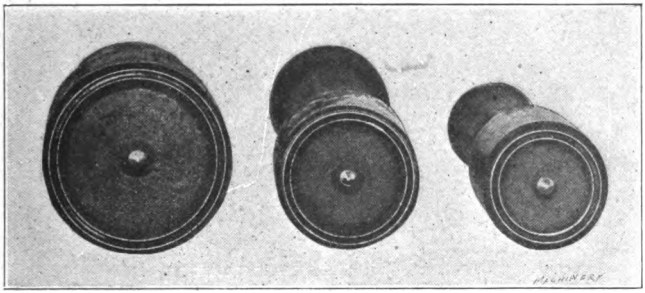

Fig. 6. Special Punches used for Laying out Holes

to be placed on top. As the illustration shows, the machine has three slotting heads. These can be traversed longitudinally along the bed by power and each slotting ram has a rapid power cross-movement, so that different heads can be easily and quickly adjusted to the required position. In setting up a stack of these frames, each section is placed against angle-plates at the rear which are in line with the slotter bed. All the frames are first adjusted longitudinally in order that the faces of all jaws will true up when the top frame has been planed to the lines previously scribed. The crosswise position of the work is then checked by testing the alignment of the lower frame with the bed. When this lower section is accurately located, the frames above are set by it in a crosswise direction by using a large square.

This slotting machine is operated by two men who proceed with the slotting operation in such a way that the three heads are used simultaneously as much as possible. The method of machining a stack of three-jawed frames similar to the type illustrated in Fig. 4, will illustrate how the machine is handled. One man begins slotting the shoe face *m* of the middle jaw, while the second man is rough planing the pocket *c* for the cylinder. When the first man has slotted the face of jaw *m*, he moves to the front and begins slotting shoe face *f*. In the meantime, the second man starts a finishing cut over surface *c*, and then begins work on the bracket pads *b* with the third head. The

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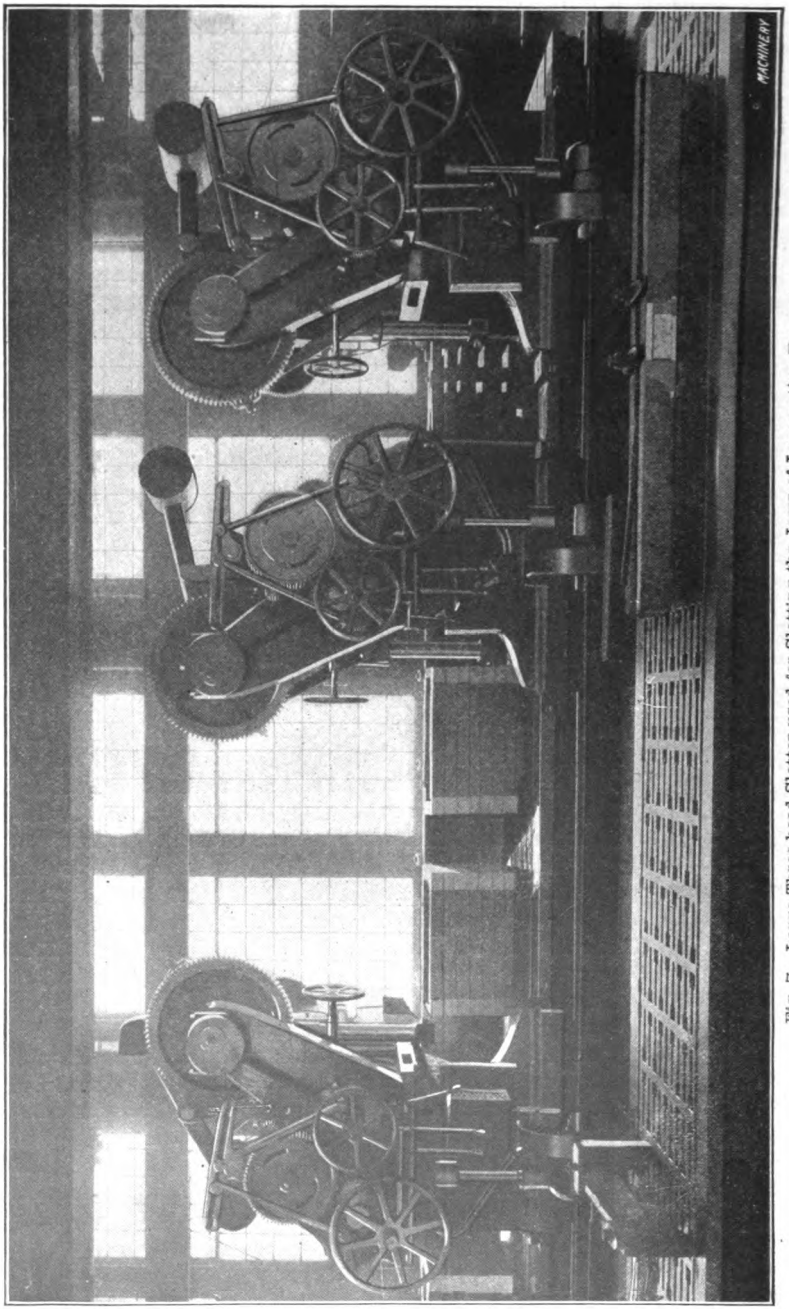

Fig. 7. Large Three-head Slotter used for Slotting the Jaws of Locomotive Frames

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reason the first man moves from the central jaw to the front, is that he is then in a position to watch the slotting head which has been started on a finishing cut along pocket *c* by the second man. In this way the two men shift from one point to another, the order of the operations depending, of course, on the arrangement or design of the frames being machined.

Fig. 8 is a detailed view, showing one of the three slotter heads. The slotting ram and its reciprocating mechanism is carried by a slide *S* which can be traversed laterally along the cross-rail shown. The rapid-traverse movements of this slide and also the power movements for shifting

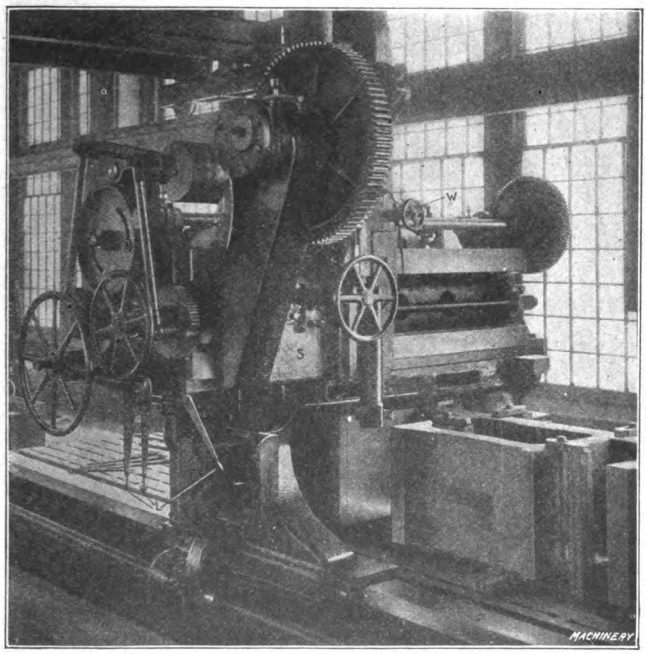

Fig. 8. Detail View of One of the Slotter Heads—Seven Frames are being Slotted simultaneously

the entire head longitudinally along the bed, are controlled by the vertical levers *L* seen at the left end of the cross-rail. This view shows the slotting tool just beginning a cut across the front or shoe face of the jaws. After the shoe faces *f*, *m* and *r* (which are square with the top of the frame) have been sotted, the tapering wedge faces *w* are finished. As those familiar with the construction of locomotives know, one side of the frame jaws is made tapering to provide an adjustment for taking up lost motion between the driving-wheel boxes and the frame shoes. It might also be mentioned, incidentally, that the rear jaws are given this taper rather than the front ones, because the latter are subjected to a greater pressure when the engine is running ahead, and it is better to have this pressure against a vertical surface than one that is tapering. The taper or wedge side is planed, on this particular slotter, by

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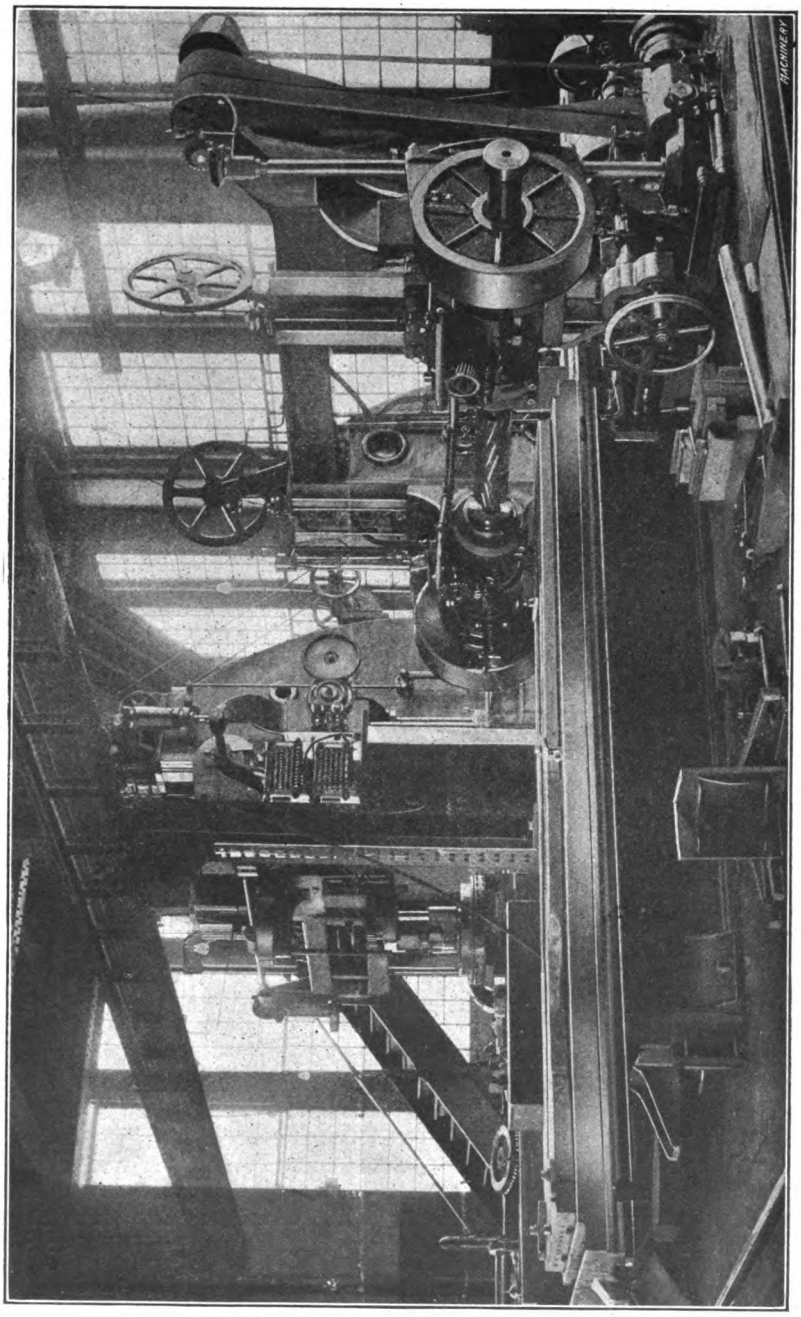

Fig. 9. Horizontal Milling Machine on which Trailer Frames are Milled

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swiveling the cross-rail, on which the ram is mounted, to the required angle as indicated by suitable graduations. The slotting operation also includes the finishing of the top surfaces *d*, as well as the lower ends of the pedestals for the braces *e* which are bolted across each pair of jaws. In order to strengthen the frames, all corners have large fillets, and when these are being formed the slotting tools are turned by swiveling the tool-bar about its axis, the handwheel *W* (Fig. 8) being used for this purpose.

The most important part of frame slotting, from a standpoint of accuracy, is that of planing the square shoe faces, which must be finished the right distance from each other, within close limits, because

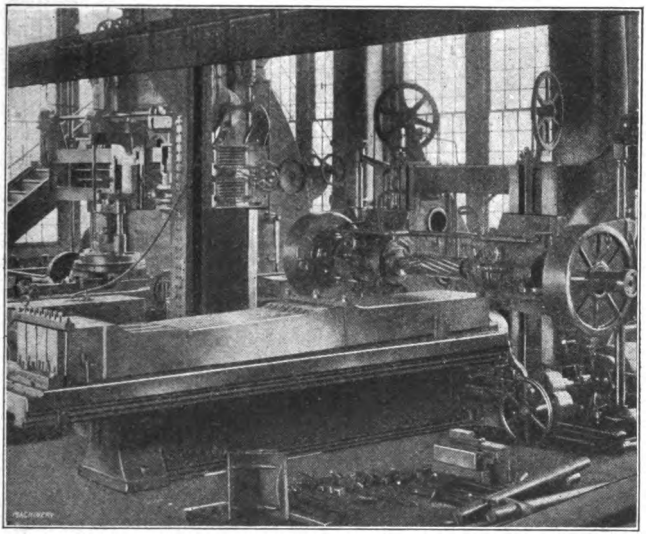

Fig. 10. Eight Trailer Frames set up for Milling the Edges

these are the surfaces which determine the location of the driving-wheels when shoes of a standard thickness are used. Gages are used for measuring these distances, the front and rear jaws being gaged from the central one which is machined first. The distance between shoulder *h* and face *f* is also carefully gaged, as this shoulder bears against the cylinder saddle and determines the longitudinal position of the frame. The jaw faces of the right and left frame sections must lie in the same plane and any irregularity in the location of shoulders *h* would affect the position of the jaws. The end *k* of each main section is also finished to provide a surface for locating the jig used for drilling the bolt holes for the trailer frame splice. Surface *k* is machined to a given distance from face *r* as shown by a fixed gage.

Milling the Trailer Frames

One of the most interesting operations on the frames is that of machining the section *T*, Fig. 4, called the "trailer" or rear frame.

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Of course, it will be understood that these trailer frames are only used on locomotives of the passenger type having trailing wheels, which differ from the drivers in that they simply carry weight and are not connected by the side-rods. The trailer frames are forged and they are finished on the sides and edges in the powerful horizontal milling machine shown in Fig. 9. These forgings are not made very close to the finished size, because with the improved milling practice, the metal is removed so rapidly that it would not be economical to forge too close to the finished dimensions. The amount of metal removed in

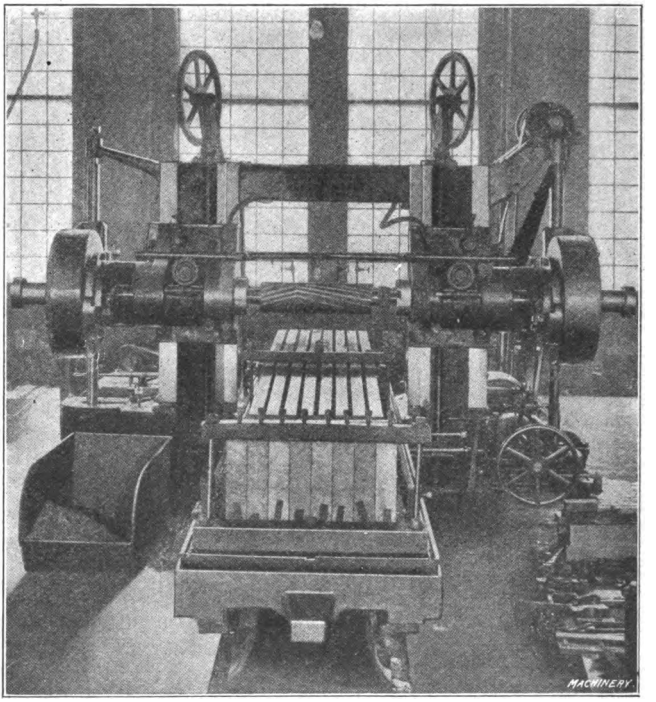

Fig. 11. End View of Trailer Frames and Milling Machine

machining these frames is indicated by the fact that a rough frame weighs about 2212 pounds, whereas one that is finished weighs only 1725 pounds. The frames are first milled on the sides, two being placed on the machine at one time as illustrated in Fig. 9. The work is shimmed up with liners or thin wedges and held by ordinary clamps as shown. A stop-bar is placed across the outer end to take the thrust of the cut. As the milling cutter advances, the clamps are shifted from one point to another. The cutter used is 33 inches wide, and when the edges are being milled, practically the entire width of this cutter is in use. It consists of three 11-inch units having inserted blades which are held in accurate helical grooves, giving a constant cutting angle for the full width of the blade. These cutters are made

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in the Juniata shops and they are partly responsible for the efficient milling practice in connection with frame and rod work.

After both sides of all the frames in a lot have been machined, the edges are milled to the proper contour. At the present time, eight of these frames are milled on the edges simultaneously. The way the work is set up is indicated in Figs. 10, 11 and 12. Two broad clamps are placed across the top and the frames are held laterally by screw-stops along the sides. The rear clamp is provided with eight set-screws which insure a bearing on each frame section. The outer frame on the operator's side has lines showing the required outline for the finished edges. These lines are transferred from a steel templet before

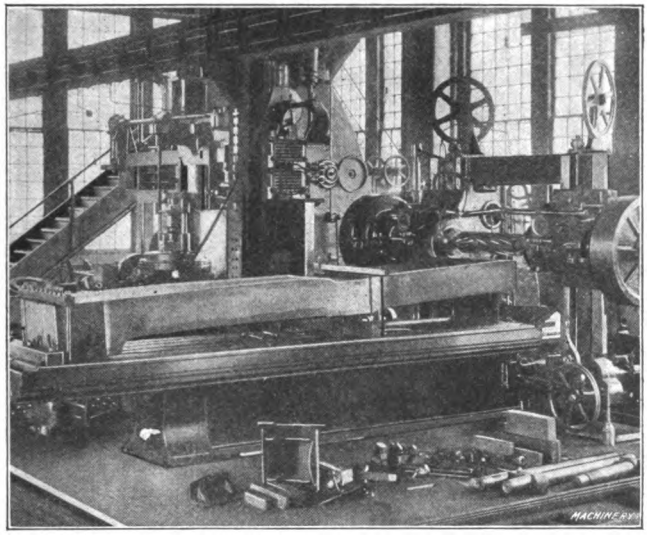

Fig. 12. Stack of Trailer Frames blocked up for Milling Taper End

the frames are placed on the machine. The frames are first set up as shown in Fig. 10, and are then turned over for milling the opposite edges. As section F, Fig. 13, and middle section I, are tapering, it is necessary to block up the work as indicated in Fig. 12, in order to secure a straight tapering surface. This particular illustration shows the frames set for milling the tapered end F, Fig. 13. The irregular outline at the center and the radius at the wide end, are formed by adjusting the milling cutter vertically by hand as the work feeds forward.

In order to show how rapidly these rough forgings are machined to the proper size and shape, we shall give the actual time required for milling the various surfaces of the frames and the approximate depth of the cut. The various surfaces to which the data refers are marked in Fig. 13 by letters, and the lengths in each case are also given. Part A having a length of 5 feet 8½ inches is milled in 56 minutes, and the average cut varies in depth from ½ to ⅜ inch. Of

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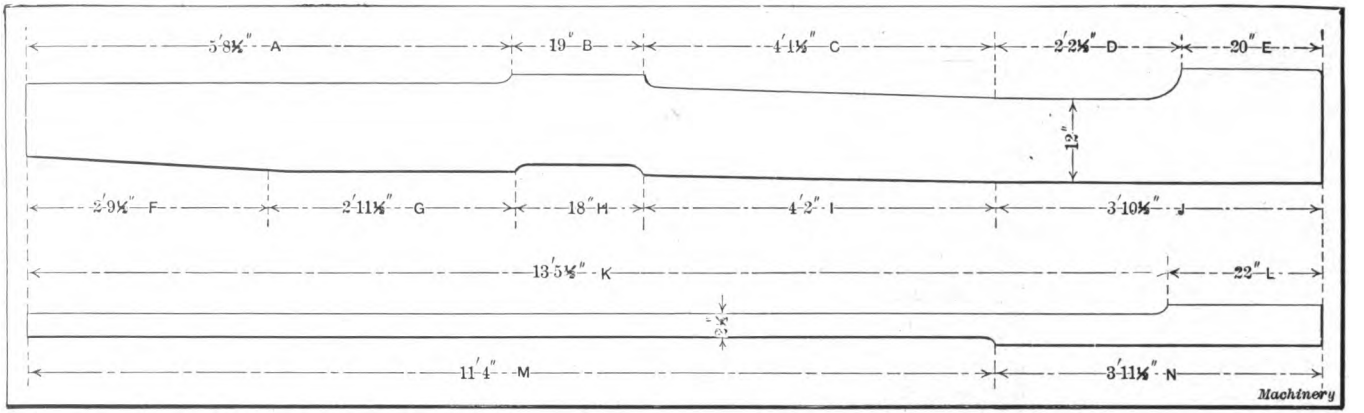

Fig. 18. Diagram showing Lengths of Milled Sections—Data covering Time and Average Depth of Cut is given in Text

course it will be understood that the time specified is for eight frames, so that if we only consider one frame, section A is milled in 7 minutes. The time taken for section B is 21 minutes and the depth of cut varies from ¾ to ⅞ inch; section C is 1 hour 6 minutes, depth of cut ¾ to ⅞ inch; section D, time 43 minutes, depth of cut ⅝ inch; section E is finished by planing prior to milling operation; section F, time 1 hour 40 minutes, depth of cut ½ to 2½ inches; section G, time 28 minutes, depth of cut ⅜ to 1 inch; section H, time 41 minutes, depth of cut, 1½ to 2½ inches; section I, 34 minutes, depth of cut ¼ to ⅞ inch; section J is finished by planing; section K, time 1 hour 15 minutes, depth of cut ⅛ to ½ inch; section L is finished by planing; section M, time 55 minutes, depth of cut ⅛ to ⅜ inch; section N is finished by planing. The time given for milling the sides K and M is for two frames. The amount of metal removed from the edges of the eight frames is approximately 1356 pounds, whereas 2542 pounds are removed from the sides, giving a total of 3898 pounds. The total time required for milling the edges is 6 hours 29 minutes and for the sides, 8 hours 40 minutes, giving a total cutting time of 15 hours 9 minutes for eight frames, so that the amount of metal removed per hour of cutting time is approximately 257 pounds. It should be mentioned

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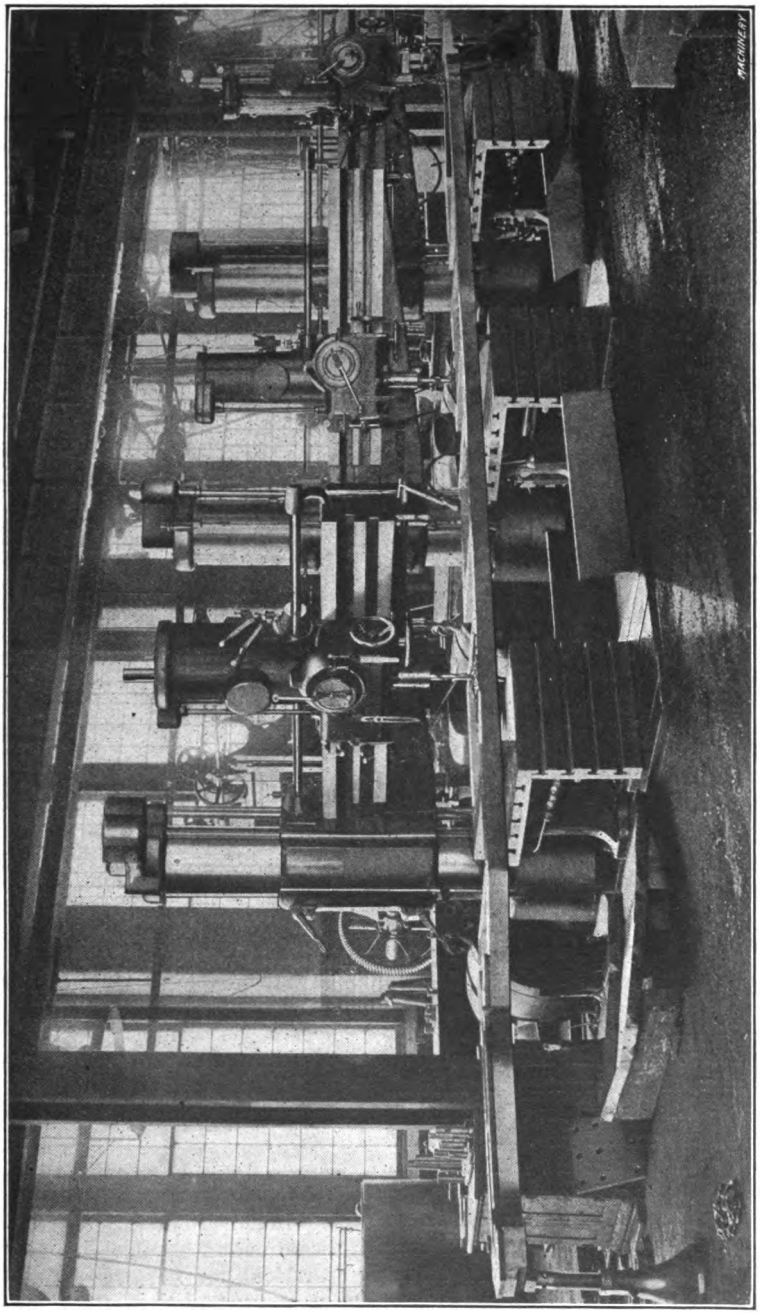

Fig. 14. Gang of Three Radial Drilling Machines used for Locomotive Frame Work

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that the foregoing figures do not cover the time required for setting and clamping the work on the machine.

Drilling and Finishing the Frames

There are a great many parts attached to the frames, such as brackets for the spring and brake rigging, stiffening braces, pedestal braces and many other parts, all of which require bolt holes, so that the drill press work is quite extensive, as is indicated in Fig. 4. Three large radial drilling machines are used for this work. The frame is first set up for drilling all the side holes, as shown in Fig. 14, and it

Fig. 15. Rounding the Corners of a Frame prior to Erecting

is then placed in a vertical position for drilling the pedestal-brace bolt holes. Most of the holes are drilled by the use of plate jigs which are located by previously machined surfaces and, in some instances, by lines drawn for this purpose when the frame is laid out. High-speed steel drills are used and these are flooded with soda water so that very rapid work is possible. As it is important to have accurately fitting frame bolts, the various holes are finished by reaming at the time the frames are erected, as will be described later.

After the frames are drilled they are removed from the machine shop to the erecting department, as the work has now progressed to the point where it is ready for assembling. Before referring to this last step in connection with the framework, attention should be called to the fact that all of these different operations are performed progressively, the work being advanced from one machine to the next

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without making any retrograde or backward movements. This is also true of other classes of work, the machines being arranged, as far as possible, so that the work moves along in a direct line as it passes from the stock pile to the various machines and, finally, to the place

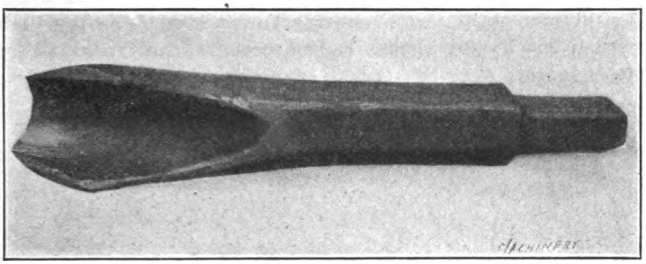

Fig. 16. Gouge-shaped Chisel used for Rounding Corners

where it is to be assembled. When we consider how many parts are incorporated in a single modern locomotive and then remember that approximately one such locomotive is being built daily at the Juniata shops, the importance of direct methods and their bearing on the rate of production can readily be appreciated.

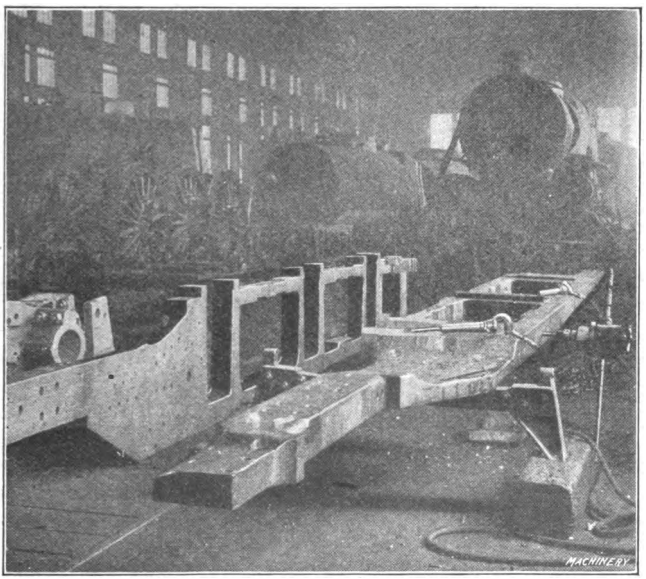

Fig. 17. Frames after the Chipping is Completed

When the frames reach the erecting department, all corners are rounded by pneumatic hammers (as indicated in Fig. 15) before assembling. The chisels used for this work are shown in Fig. 16. They are shaped somewhat like a gouge but have a concave cutting edge. The corners are finished to the required radius by a single cut and

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almost as smoothly and neatly as could be done in a planer with a form tool. Two frames which have been finished in this way and are ready for the erecting gang, are shown in Fig. 17. This rounding of corners gives the frames a finished appearance and also makes it much easier to handle them, as all sharp edges have been cut away. It is also thought that a frame having round corners is less liable to fracture than one having square ragged corners, the theory being that a minute indentation at the corner may, in time, develop a fracture.

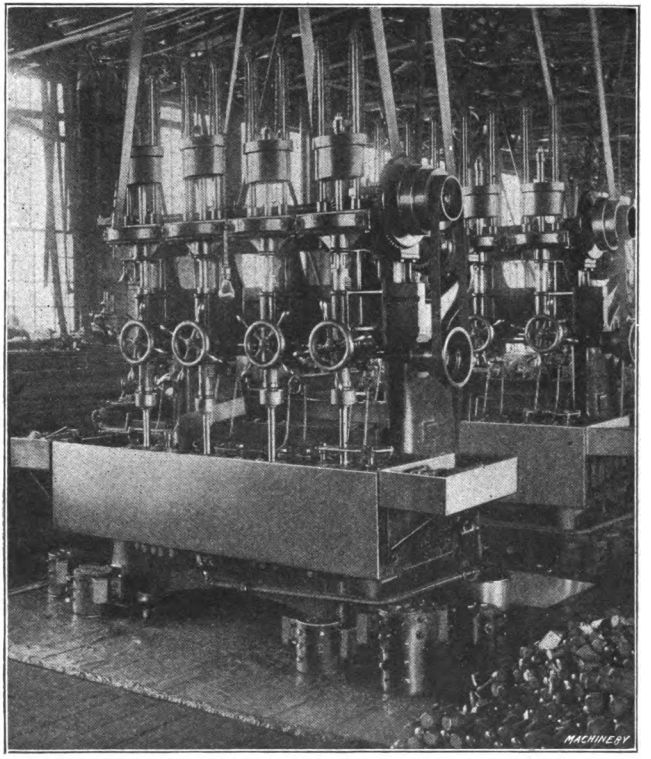

Fig. 18. Special Machine for Turning the Frame Bolts

The main frame and the trailer frame (in this particular case) are next aligned and the bolt holes for the splice at *A*, Fig. 4, are reamed. After the splice bolts are inserted, the right and left frame sections are tied together by the different cross-braces, and this is the first step in erecting a locomotive. The two sections are mounted on blocks and jacks and are then set level and parallel with each other. The various cross-ties and braces are temporarily clamped in position for reaming the previously drilled holes. As all the parts are accurately drilled, the holes are usually in close alignment, so that little reaming is necessary to produce a smooth hole which will insure an even bearing throughout the length of the bolt.

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The reaming is done by means of an air motor, and the time required for reaming a hole and driving a bolt "home" is a matter of seconds rather than minutes. The reamer is entered into the hole and the motor-driven chuck is applied to the end. As the reamer only has a taper of 3/32 inch per foot (which is the standard for all frame bolts), it is quickly fed to the required depth. The reamer is then backed out while it rotates in the same direction, and the chips are blown from the hole by turning the air exhaust of the motor into it. A standard bolt is next inserted and driven home by a few blows of the sledge.

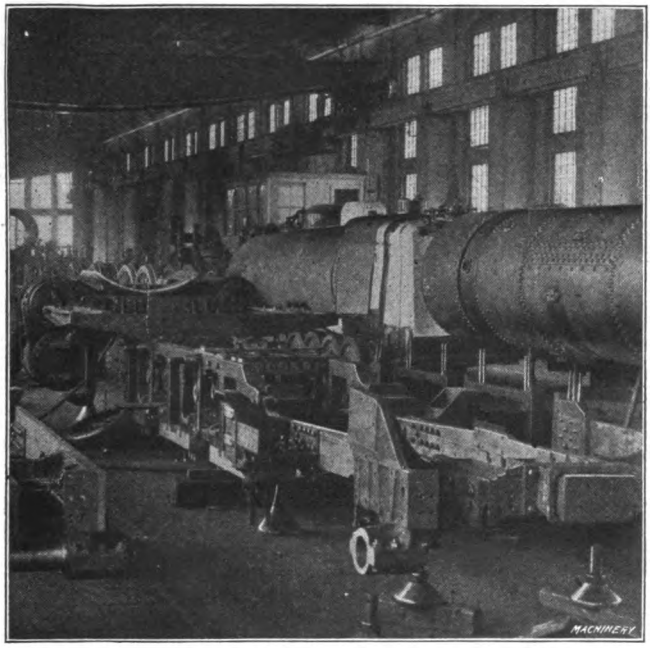

Fig. 19. Frame after Cylinders, Braces and other Parts have been assembled

This entire operation of reaming the hole, cleaning it and driving in the bolt, is done in a surprisingly short time. As these men are constantly at this work, they have become very expert. No gages are required for reaming, as the workmen know just how far to feed in the reamer for any given bolt. When a hole is being reamed, the motor is held by two men, while a third man measures the distance between the reamer driving chuck and the frame in order to determine when the reamer has reached the required depth. When a reamer becomes too dull to work effectively, it is sharpened in a special grinding machine. The importance of keeping the reamers in good condition can best be appreciated by those who have tried to true up a hole with a dull reamer. Before the erection of the frames is complete, they must be bolted to the cylinder castings which form the principal support at

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the front. Fig. 19 shows an assembled frame after the cylinders, braces, guide-yoke and other parts connected with the spring and brake rigging, have been attached. When the work has reached this stage, it is only a matter of a few hours when the frame will be buried behind the driving wheels of the assembled locomotive.

Turning Frame Bolts

The method of turning the frame bolts used in assembling the frames is interesting, owing to the rapidity and simplicity of the operation. The machine used resembles an ordinary four-spindle drilling machine, as will be seen by referring to Fig. 18. The spindles are equipped with chucks having hexagonal pockets, not unlike a socket wrench, which fit the heads of the bolts and cause them to revolve while the body is being turned. The turning is done by cutter heads located in the base. There are two heads for roughing and a similar number for finishing. The roughing heads have two blades or cutters which are about 5/16 inch or 3/8 inch thick and 1¼ inch long. These cutters are set diametrically opposite, and they remove the hard outer scale. The bolt body is rough turned close to the finished size, but this first operation leaves it straight or of one diameter throughout. The work is then placed in a finishing head. These heads also contain two cutters which differ from those used in the roughing heads in that they are as long, or longer, than the bolt body and are set to turn the bolt body to the required taper. The turning operation, in each case, is performed by feeding the revolving bolt down through a cutter head just as a drill would be fed through its work. Several of these cutter heads may be seen at the base of the machine. They are mounted in floating holders so that they can adjust themselves to the bolt being turned. Very rapid work can be done in this machine, one man keeping the four heads in operation. The threading of the bolts is done in regular bolt-threading machines.

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CHAPTER II

MACHINING LOCOMOTIVE CYLINDERS*

The cylinders of locomotives vary considerably in their general arrangement, and the exact method of machining them depends altogether on the type; but as the variations in practice are of minor importance, we shall deal with the subject in a general way instead of describing in detail the operations for each particular design. The various operations referred to represent the practice at the Juniata shops of the Pennsylvania Railroad, where all the passenger locomotives and many of the freight class used in this extensive system are built.

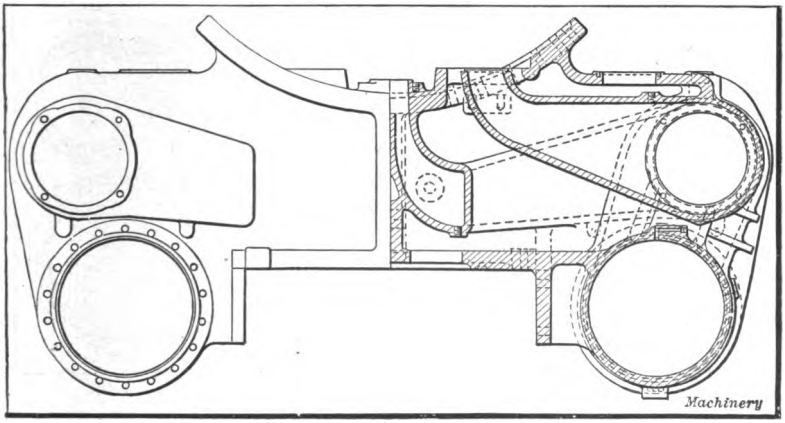

Fig. 20. Front View of Locomotive Cylinders of the Single-expansion Piston Valve Type

The style of cylinder now used almost exclusively on the new locomotives built by the Pennsylvania Railroad is the single-expansion piston-valve type. Figs. 20 and 21 show two designs which differ in that the cylinders illustrated in Fig. 20 are cast integral with the saddle, whereas the cylinders shown in Fig. 21 are bolted to the saddle which forms a separate casting. The advantage of this three-piece construction is that a broken cylinder can be replaced more quickly because the saddle does not need to be detached from the boiler or frames. With the design shown in Fig. 20, considerable time is required to fit and bolt the flange on the saddle of a new cylinder to the boiler.

Boring the Cylinders

The first machining operation on a cylinder casting is that of boring the cylinder proper. The boring is done by the large machine illustrated in Figs. 22 and 24. The cylinder casting is supported at the

* MACHINERY, Railway Edition, April, 1912.

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right height by a fixture, as shown. The flanges are first rough-faced by radial facing arms *A* and *B*, the tools of which are fed by the well-known star feed. The bore is then finished by one roughing and one finishing cut, four tools being used for roughing and two for finishing. Broad-nosed tools are used for the light finishing cut and are given a feed of ⅜ inch per revolution of the boring-bar. As the boring-bar is very rigid, these coarse feeds can be used without chattering. The cylinder is also counterbored as far in as the inner edge of the steam ports, to prevent the piston-rings from wearing shoulders at the ends of the piston stroke.

After the cylinder bore is finished, the table or platen of the boring machine is moved over the right distance for boring the valve chamber,

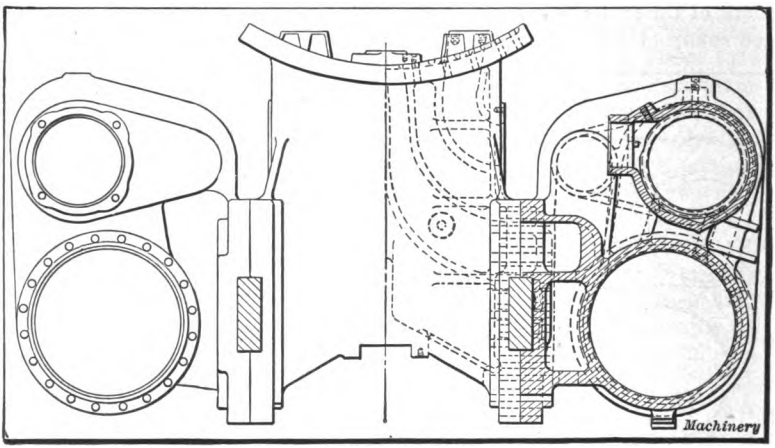

Fig. 21. Locomotive Cylinders having a Detached Saddle

the proper adjustment being determined by graduation lines at the side of the table. In order that the valve chamber will be at the proper vertical height after making this adjustment, the casting is originally set up in the machine so that the centers of the cylinder and valve chamber are in the same horizontal plane. Fig. 24 shows the position of the work when set for boring the valve chamber. The flanges are faced prior to boring, and the offset of the flanges with relation to the cylinder flanges, is tested by a special gage. The valve chambers are not bored to one diameter throughout, but have a shoulder at each end for locating the valve bushings or linings which are afterward forced into the bore. The piston-valve operates inside these bushings, which can readily be renewed when worn. As the steam ports are machined in the bushings, the latter must be accurately located lengthwise to bring the ports in the right position. The proper location for each bushing is secured by the shoulder previously referred to, in conjunction with corresponding shoulders on the bushings; hence this shoulder in the bore must be accurately located by another special gage.

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Planing the Cylinders

After the cylinder is bored, the various surfaces on the saddle are planed. By the use of an ingenious set of fixtures, the castings are quickly and accurately set up for the planing operations. Fig. 23 shows the cylinder planer with these fixtures in place, and Figs. 25, 26, and 28 show different views of the work mounted on the fixtures. Three cylinders are placed in a row and planed simultaneously, and the fixtures are so arranged that the bores of the various cylinders are aligned with one another and with the planer platen. These fixtures consist of heavy brackets or standards *B* having flanges as shown. The end brackets have a single flange, whereas the two which come between

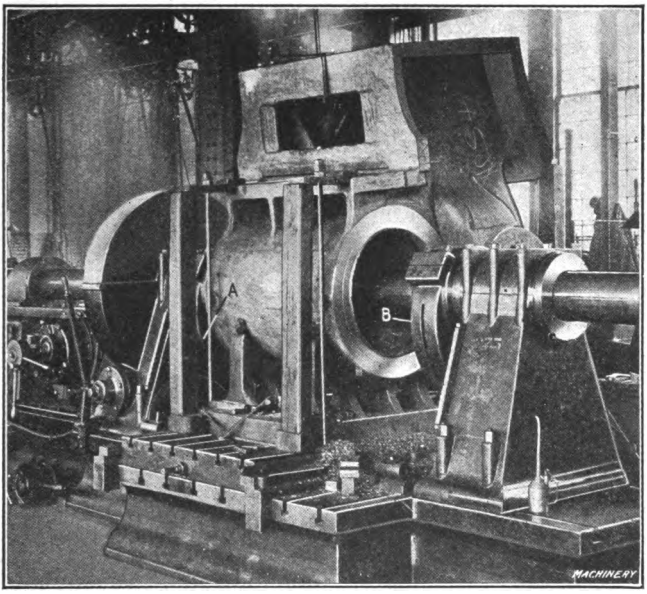

Fig. 22. Boring a Locomotive Cylinder

the cylinders are double flanged. There is a central pocket *A* in each flange face, and the distance from these pockets to the base is exactly the same for each bracket. Each of the conical disks *C* which engage the counterbores of the cylinders, has a cylindrical boss *D* on the rear side which fits into any of the central pockets *A*. When a cylinder is to be set up for planing, one of these conical disks is clamped in each end of the counterbore by a bolt passing from one disk to the other. The brackets are also bolted to the planer platen in the proper position, as indicated in the illustration. The distance between the brackets is governed by the length between the outer faces of the disks after the latter are bolted in place, and the central pockets *A* are all brought into alignment, laterally, by tongue-pieces on the base of each bracket. The cylinder is next picked up by a crane and lowered until the disks have entered between the brackets. The temporary holding bolt for

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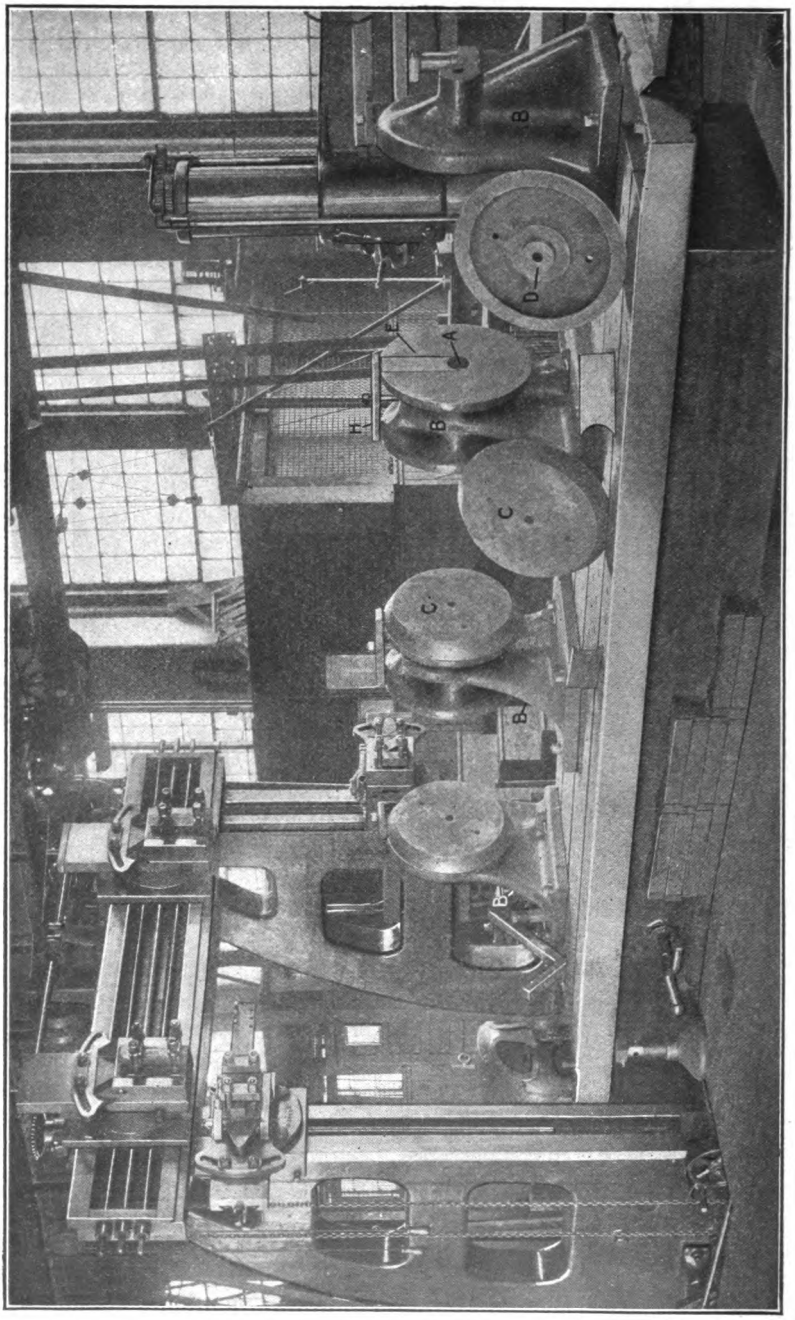

Fig. 28. Fixture for Holding Cylinders while Planing

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the disks is then removed and the work is lowered until the cylindrical bosses *D* on the disks, which slide through the vertical slots at *E*, rest in the central pockets *A* of the fixtures. When three cylinder castings have been set up in this way, the center line or axis of each cylinder bore will be in alignment.

The valve chamber is next set vertically with relation to the center of the cylinder. To obtain this setting, a spider *F*, Fig. 25, is placed in the valve chamber and its hub is centered with the bore of the valve chamber by using hermaphrodite calipers. The casting is then adjusted vertically by the small supporting jacks seen in Fig. 28, until this center is the required distance below the center of the cylinder, as shown by

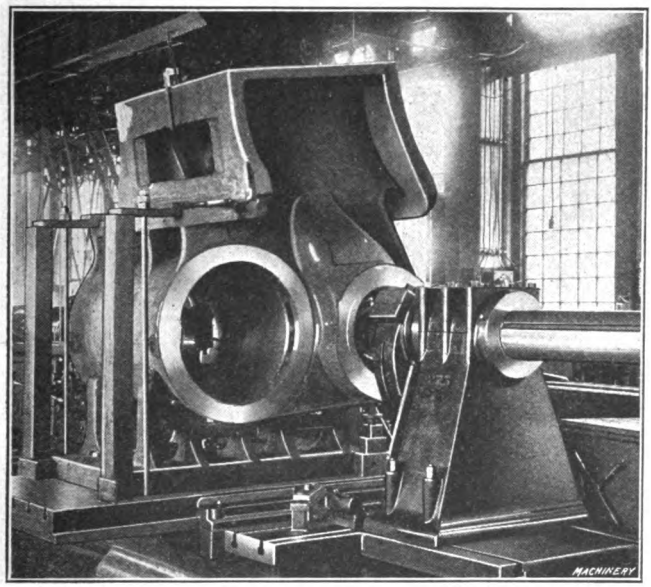

Fig. 24. Cylinder set for Boring Valve Chamber

an ordinary surface gage. The height from the platen to the center of th cylinder bore is accurately ascertained beforehand and remains constant for a given size fixture. After the three castings are set as described, clamping pieces which fit in the slots *E*, Fig. 23, are tightened against the hubs of the conical disks by clamps *H*. The cylinders are further secured by a long tie-bolt *G*, Fig. 25, which extends through the three castings and holds both the work and fixtures rigidly together. The side view, Fig. 26, clearly shows how the conical disks enter the cylinder counterbores and align the three castings. By referring to Figs. 25 and 28, it will be seen that these fixtures make it possible to hold the three cylinders with very few clamps; in fact, the four clamps in Fig. 28 are (with the exception of clamps *H*, Fig. 23, which are part of the fixture) the only ones required. These fixtures have not only effected a considerable reduction in the time required for setting the

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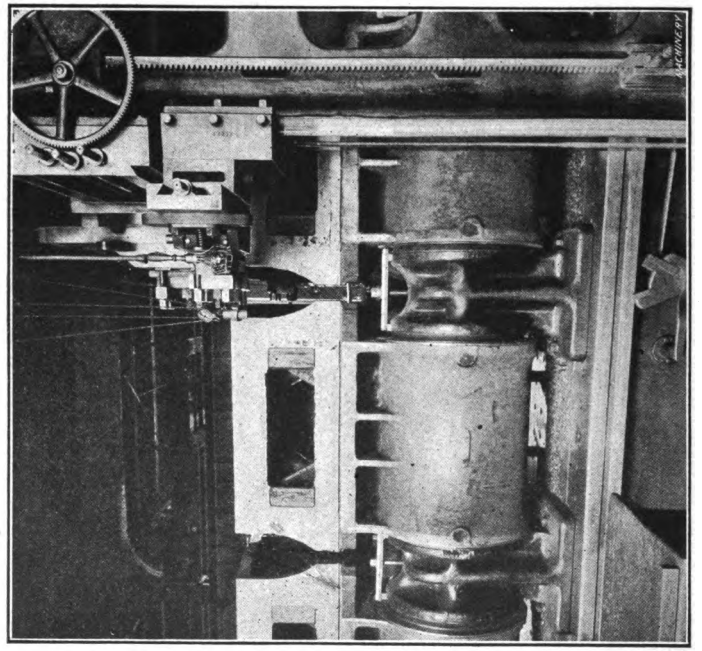

Fig. 26. Side View showing Arrangement of Planing Fixtures

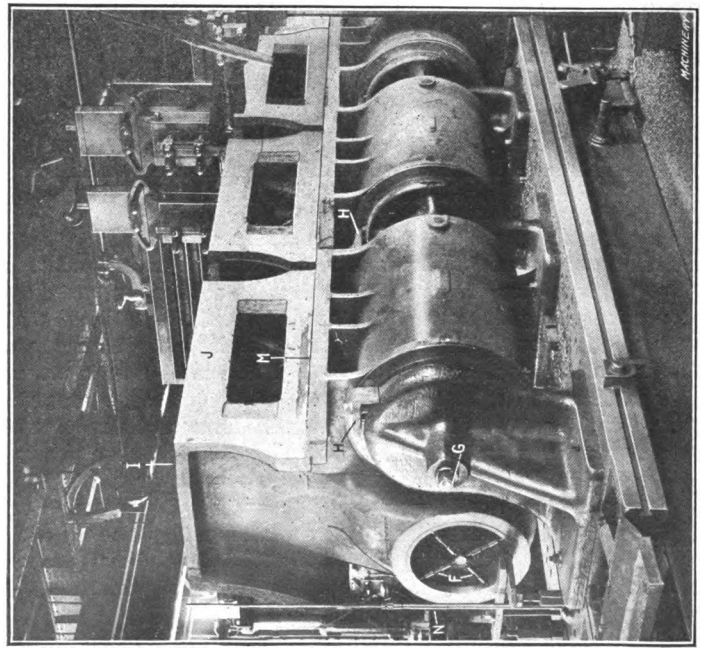

Fig. 25. Three Cylinders being planed simultaneously

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cylinders prior to planing, but they also insure accurate and uniform work.

After the cylinders are set as described, the top surface *I*, Fig. 25, which forms the joint between the right- and left-hand cylinders, is rough-planed by using the two tool-heads. This surface is then finished with a broad tool which is set to the right height for the final cut by a special micrometer gage *N*. The cutting edge is adjusted to coincide with the top of this gage, which is graduated with reference to the centers of the fixtures so that heights from the center of the cylinder bore can be read directly. The side *J* is next roughed out and finished

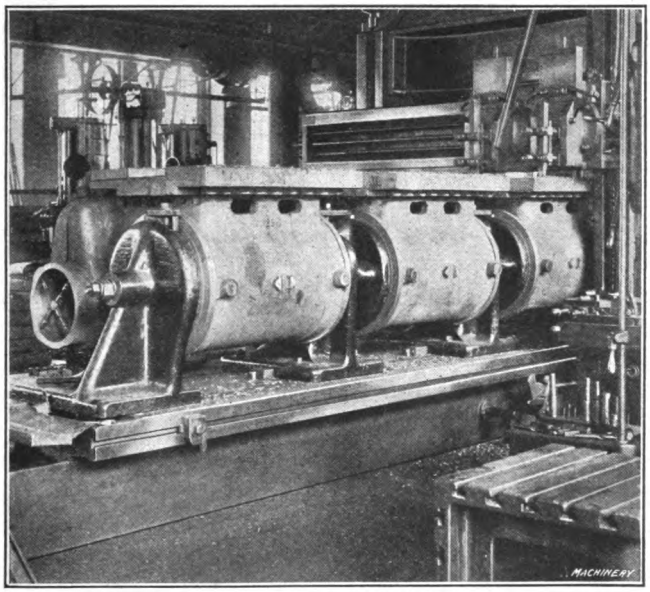

Fig. 27. Planing Cylinders of the "Three-piece" Type

by using a side-head, and while this surface is being planed, the seats *K* and *L* (Fig. 28) for the steam and exhaust pipes, are rough-planed with the opposite side-head. Side *J* is finished to a certain distance from the planer housing, the measurement being taken with a special vernier gage. By measuring directly from the housing, duplicate work is assured and the liability of mistakes is lessened. This method of measuring is made practicable by the improved fixtures, which are always located in the same lateral position on the platen and, consequently, hold the finished cylinder bores in the same vertical and crosswise position. The face *M*, against which the frame is bolted subsequently, is planed at the same time the seats *K* and *L* are finished. The half-seat *K* for the exhaust pipe, is gaged from the finished side *J* and the steam pipe seat *L* is finished with reference to the exhaust seat. The distance between surfaces *I* and *M* is measured by a special height gage. This practically completes the planer work. Of course, the order

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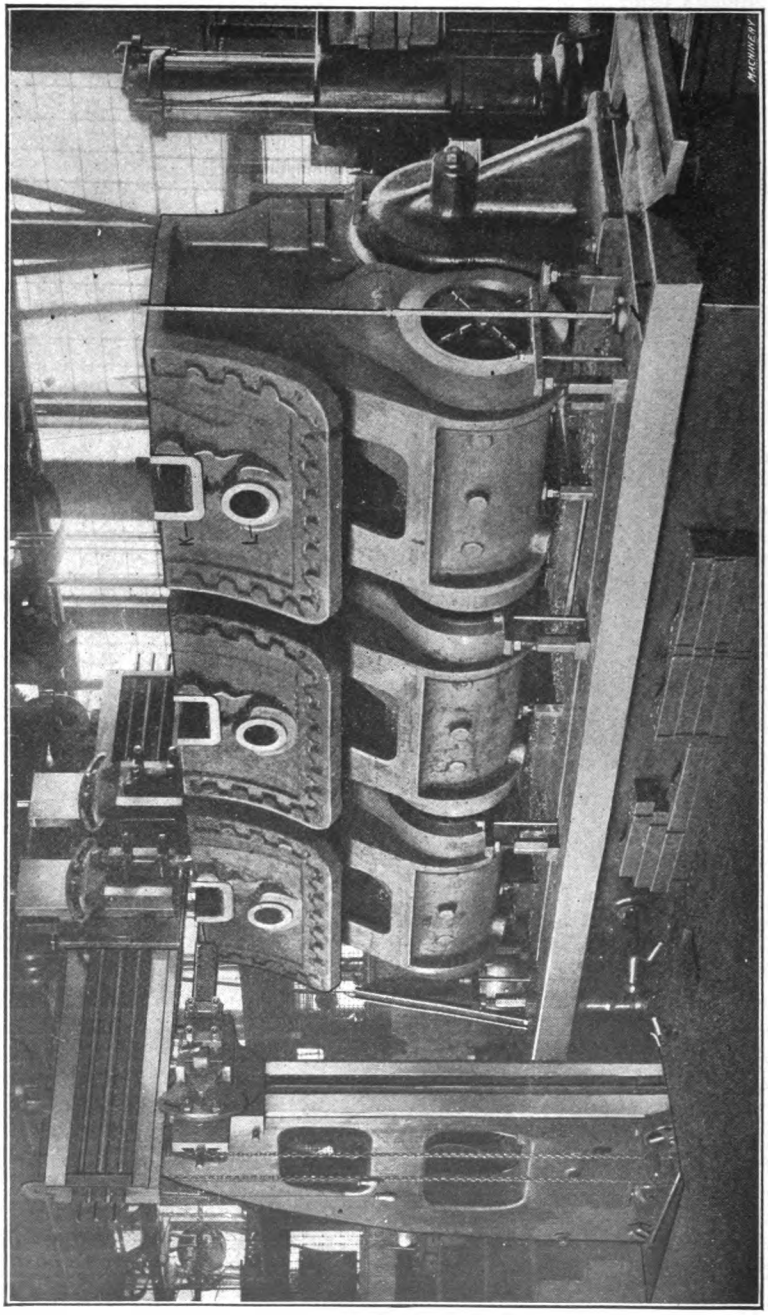

Fig. 28. General View of Cylinder Planer—Note Small Number of Clamps used for Holding Work

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of the operations is governed entirely by the shape of the cylinder casting, and differs from that described in the foregoing, for other types of cylinders.

Figs. 27 and 29 indicate the method of planing cylinders of the type illustrated in Fig. 21, which, as will be recalled, are bolted to the saddle. These castings are set up in the same way as described for the style illustrated in Fig. 28. The planer work on the cylinder proper is more easily done owing to the shape of the casting. The illustrations shows the two cross-rail heads rough-planing the saddle joint, while the left side-head is planing small pads on the steam chest. The

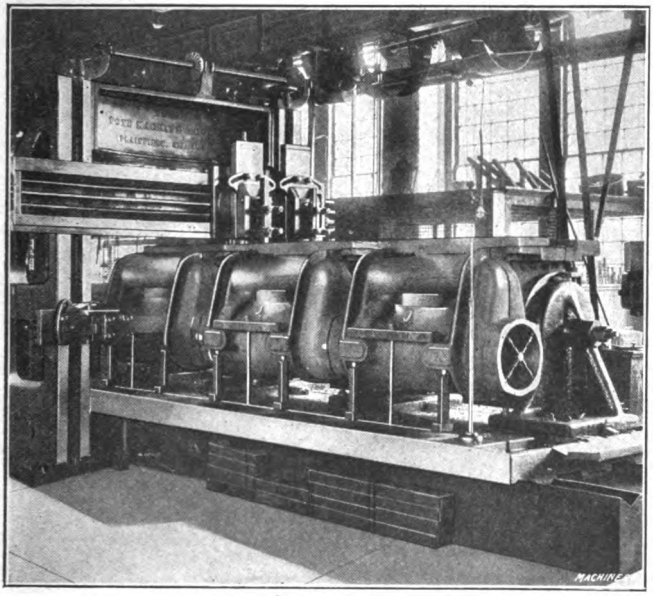

Fig. 29. Another View of the "Three-piece" Cylinders set up for Planing

tool is set for finishing the saddle joint by the same micrometer gage previously referred to, but a shorter measuring rod is inserted in the base for this particular style of cylinder. The pocket in the center of the saddle joint is finished to fit the frame, and in the right relation to the cylinder bore. There are also corresponding pockets in each side of the saddle casting, and the frames pass through the rectangular opening or mortises thus formed, as indicated by the section lines in Fig. 21. The planing of this saddle joint and pocket is practically all the planer work there is on a cylinder of this type. The nature of the planing operations on the saddle is clearly indicated by the drawing Fig. 21.

Laying Out and Drilling the Cylinders

After the cylinders are planed, the accuracy of the machine work previously done is tested and the casting is laid out for drilling holes that cannot conveniently be jig-drilled. Fig. 30 shows the method of

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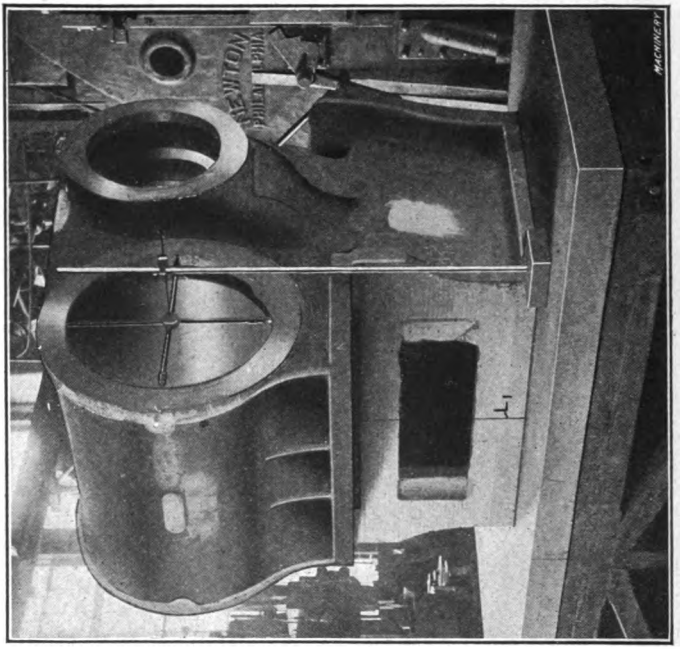

Fig. 31. Another View of Cylinder on Testing and Laying-out Plate

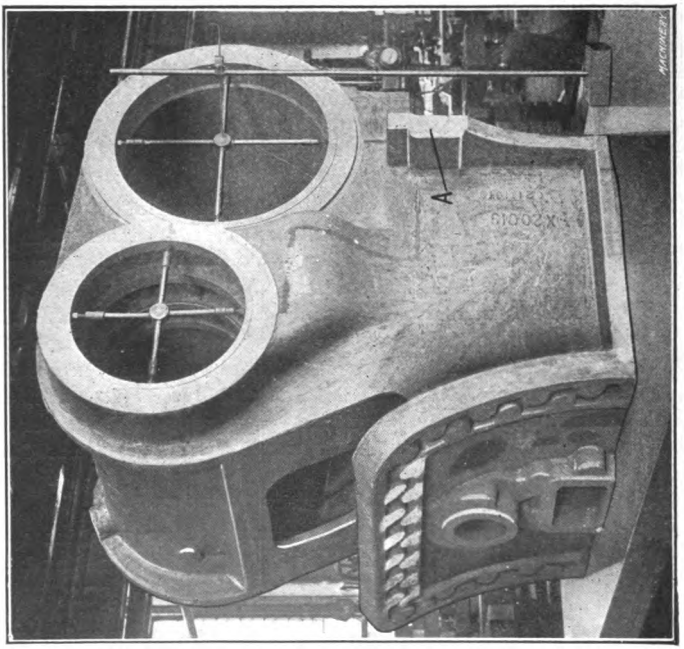

Fig. 30. Testing Height of Cylinder and Valve Chamber

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testing the location of the cylinder bore and valve chamber with relation to each other and to the finished central joint which is resting on the laying-out plate. The centering spiders shown are first accurately set in each bore and the respective heights of the cylinder and valve chamber are determined by using a tall surface gage. These heights are measured by comparing the gage pointer with a long steel

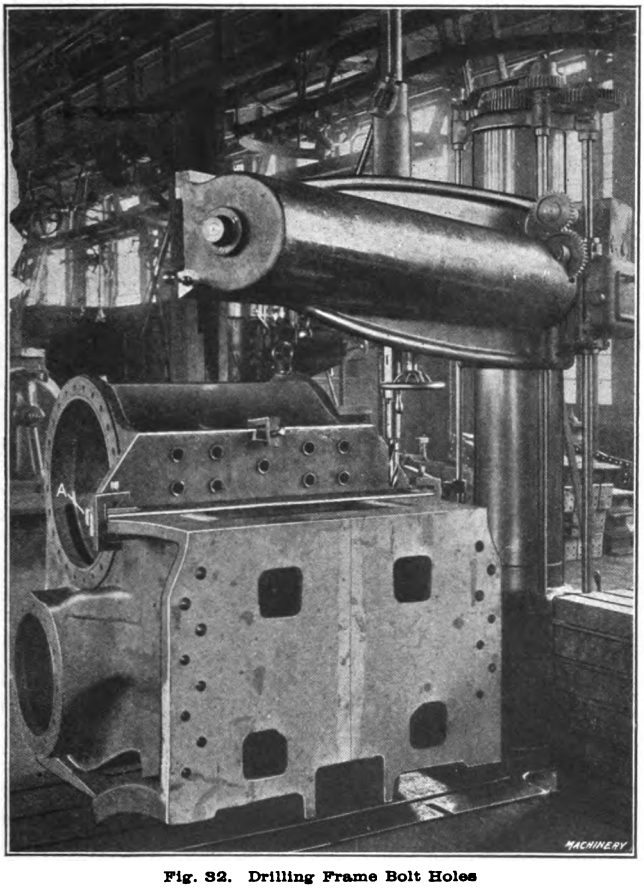

Fig. 82. Drilling Frame Bolt Holes

scale held in a vertical position. While the use of the planing fixtures previously described insures accurate work, it has been found advisable to check important dimensions so that the cylinders can be erected without delay due to imperfect work. After the height of each bore has been checked, as described, the distance from the face of the back cylinder flange to the finished projection *A* is carefully tested, as this projecting flange rests against the frame and determines the cylinder's fore-and-aft location.

Most of the holes in the cylinder are, of course, drilled by the use

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of jigs. There are, however, a few holes which cannot conveniently be drilled in this way and these are laid out at this time. For example, the small screw holes around the periphery of the flange, for fastening the cylinder jacket, as well as those for lubricator and indicator pipes, dripcocks, etc., are all laid out by hand. A center line *L* (see Fig 34) is also drawn across the saddle face for locating the jig used when

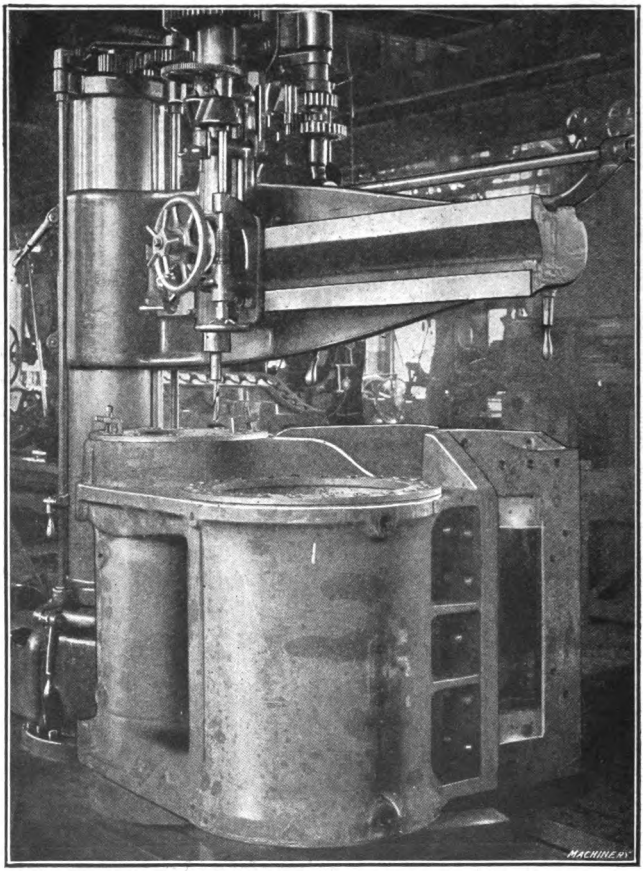

Fig. 33. Drilling Flanges

drilling the bolt holes for the steam and exhaust pipe seats at *S* and *E*. This line is exactly central with the front and back flange faces of the cylinder. A central point is first located at L_1, Fig. 31, by measuring from a long straightedge held across the front and back flanges. The cylinder is then turned over and this line is carried across the saddle joint by using a large square.

The drilling operations on the cylinder are of an obvious nature and therefore a detailed description of this work will be unnecessary. Prac-

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tically all the holes are drilled by the use of jigs in large radial machines. Fig. 32 shows a plate jig for drilling the frame bolt holes. This jig is located by the finished end *A* on the cylinder, and the jig for drilling the corresponding holes in the frame is set by a shoulder which bears against end *A*, so that both sets of holes register closely when the cylinder and frame are assembled; consequently, little reaming is necessary. The holes for the stud bolts which hold the cylinder and the steam chest heads in place, are drilled with ordinary ring jigs as indicated in Fig. 33. Fig. 34 shows the method of forming the seat for the steam pipe. This pipe is not clamped directly to the cylinder,

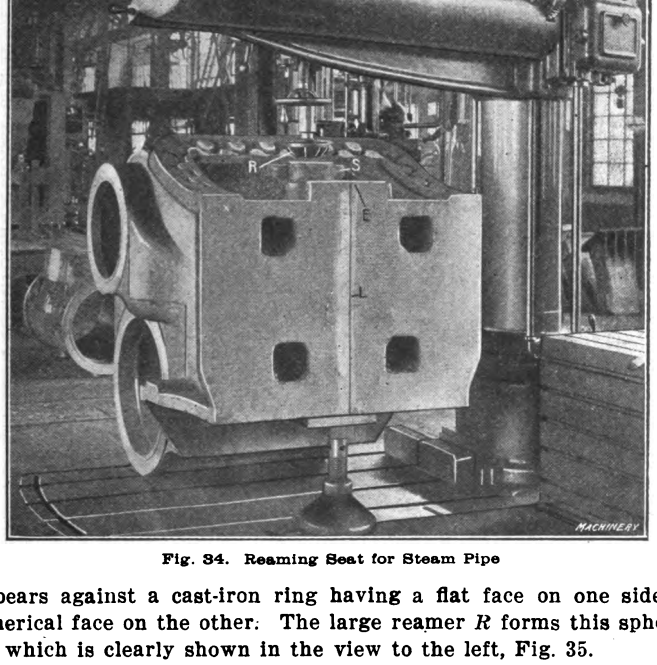

Fig. 34. Reaming Seat for Steam Pipe

but bears against a cast-iron ring having a flat face on one side and a spherical face on the other. The large reamer *R* forms this spherical seat, which is clearly shown in the view to the left, Fig. 35.

Erecting Cylinders—Piston-valve Bushings

When the drilling is completed the cylinders are ready for the erecting shop. The right- and left-hand cylinders which are to be mates, are set up and aligned as illustrated in the two views Fig. 35. The saddle bolts through the front and rear flanges *F* are then reamed and the tightly fitting taper bolts are inserted. The cylinders are now ready to be attached to the frames. They are first bolted to the frames temporarily, and their position is carefully tested. The bolt holes are next reamed and the right and left frame sections are bolted to their respective cylinders.

The bushings or linings for the valve chambers are also inserted at

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this time. There are two of these bushings in each cylinder, which are inserted from opposite ends of the valve chamber bore. The inside of the bushing is bored to fit the piston-valve, and the outside is turned to fit tightly into the cylinder. The boring is done in a vertical boring machine, and the outside is turned in a lathe (as indicated in Fig. 36), after the boring operation. The bushing is mounted on a large expanding mandrel, and it is turned from 0.002 to 0.004 inch larger than the bore of the valve chamber, in order to secure a tight fit. This allowance varies somewhat for bushings of different diameter. After the bushing is turned, the steam and exhaust ports, which are cored in the

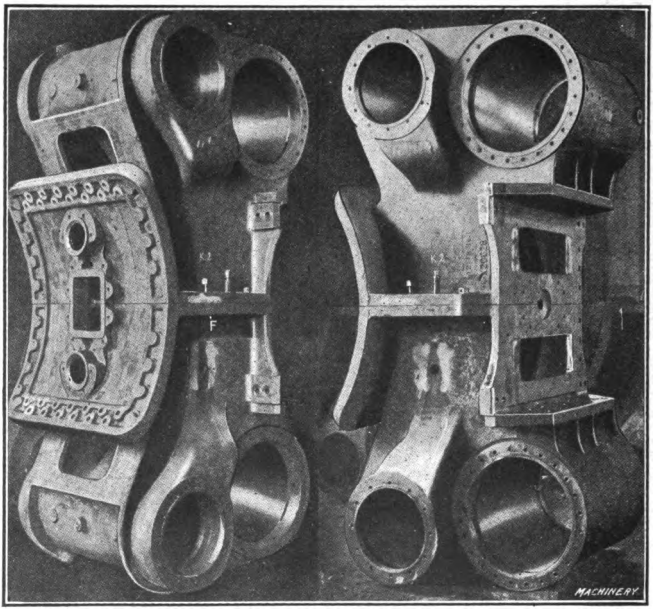

Fig. 35. Cylinders aligned for Reaming Flange Bolt Holes

casting, are finished by milling. Two finished bushings are shown to the right in Fig. 36. The large ports *E* are for the exhaust and the smaller ports *S* register with the cylinder steam ports when the bushings are in place. These ports are milled to a standard width by the use of gages. They are also located with reference to the shoulders *L* which, as previously stated, come against corresponding shoulders in the valve chamber, and determine the respective positions of the bushings. The distance between the steam ports is checked before the bushings are inserted in the cylinder. This preliminary test is made by placing the two bushings in line, with the shoulders *L* the same distance apart as the shoulders in the valve chamber. The distance between the inner edges of the steam ports is then measured with a large vernier scale *V*. A variation of only 0.004 inch is allowed for this dimension. As the distance between the packing rings of the piston-

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valves, and also the width of the rings, is accurately gaged, the proper relation between the valve and the steam ports is secured within close limits.

The finished bushings are drawn into the valve chamber by a screw and air motor as shown in Fig. 37. This particular illustration shows the motor arranged for drawing in the rear bushing. The screw, which is rotated by the motor, is prevented from moving longitudinally by a heavy strap which is placed across the flange as shown. After both bushings are drawn in against the shoulders, the distance between the steam ports is again tested with the vernier scale. This second meas-

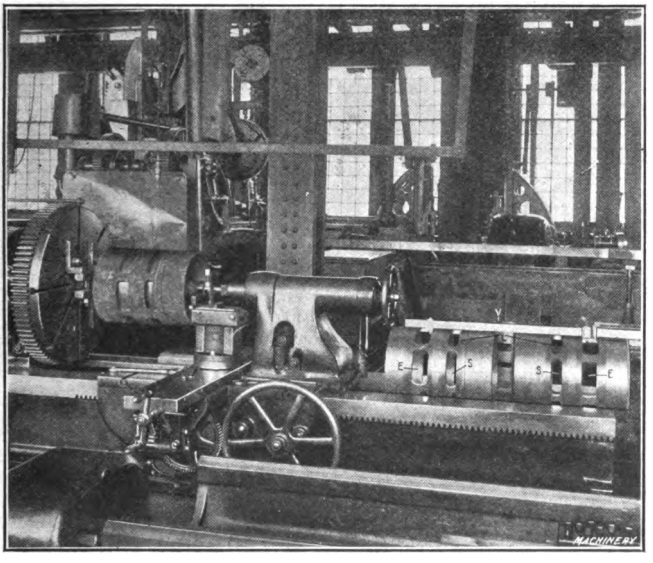

Fig. 36. Method of Turning Valve Bushings and Preliminary Test to determine Location of Steam Ports

urement is taken to make sure that the bushings are not held away from their seats by small chips or dirt which may have been overlooked when the bore was cleaned. Before the boiler can be erected, the curved seat or saddle formed by the two cylinders must be fitted to the front of the smokebox. As the steel sheet which forms the smokebox may not be exactly circular, the saddle is always fitted to the particular boiler for which it is intended. In order to obtain the required outline, the boiler is lowered by a crane onto the frames and cylinders. The boiler is then set level, both lengthwise and laterally, and it is also centered with the frames. The outline of the smokebox is then transferred to the saddle flanges, by using a scratch gage. This line represents the finished surface of the saddle, and it should be drawn just far enough from the top surface, to permit truing the entire saddle flange. When this line is scribed, the boiler is removed and a gang of men chip the flange down to the required outline. This chipping

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is done by pneumatic hammers. There are raised pads on the saddle flange as shown in the view to the left, Fig. 35, so that a comparatively small surface requires chipping. When the flange is finished, the boiler

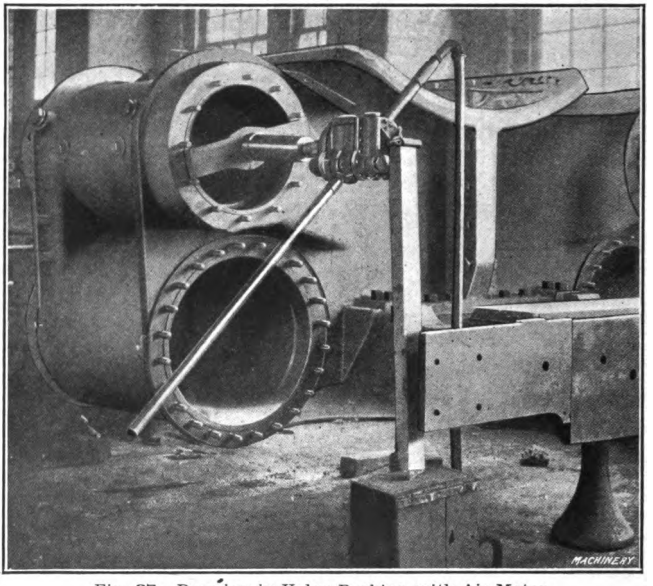

Fig. 37. Drawing in Valve Bushing with Air Motor

is permanently bolted to the cylinders, and when this stage is reached, the erection of the locomotive proceeds rapidly. The erecting practice is described in MACHINERY'S Reference Book No. 84, "Locomotive Building, Part VI."

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